SIMULATION STUDY OF THE $\bar{p}p \to \bar{\Sigma}^0\Lambda$ REACTION AT $\bar{\mathrm{P}}$ANDA AT FAIR

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ON BEHALF OF THE $\bar{\mathrm{P}}$ANDA COLLABORATION

FORSCHUNGZENTRUM JÜLICH

UPPSALA UNIVERSITY

HADRON 2019

OVERVIEW

- Introduction
- The $\overline{\text{P}}$ANDA experiment at FAIR
- Analysis strategy
- Results
- Conclusions

INTRODUCTION

Open question in QCD:

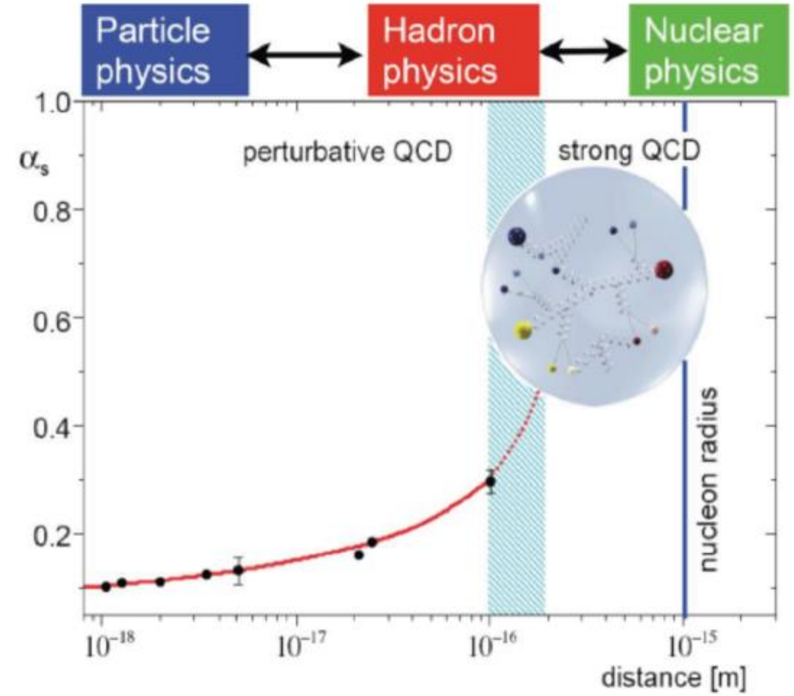
a comprehensive understanding of the strong interaction.

At high energies:

- α_s is weak
- pQCD is successful

At low and intermediate energies:

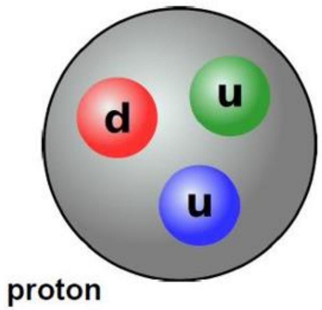
- α_s grows
- pQCD fails



To provide the effective degrees of freedom in the confinement domain is one of the challenges in modern physics

Non-perturbative QCD phenomena are connected to some of the **nucleons puzzles** *e.g.* :

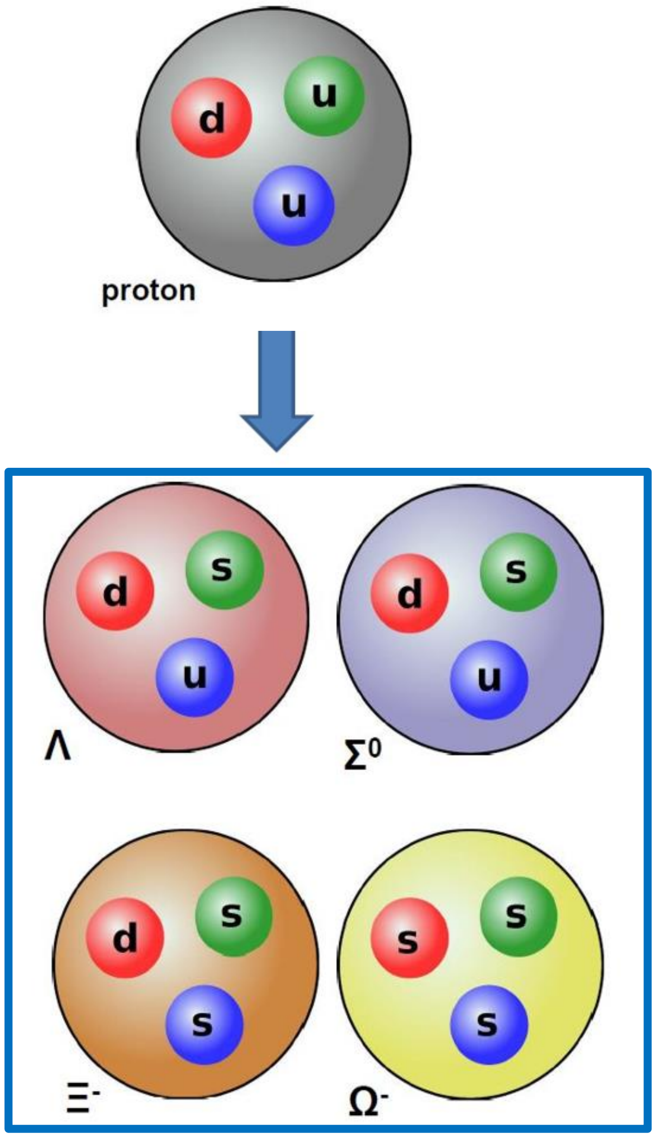
- Mass
- Spin *
- Inner structure**



*C. A. Aidala et al., RMP 85 (2013) 655-691.
** G. A. Miller, PRL 99 (2007) 112001.

Non-perturbative QCD phenomena are connected to some of the **nucleons puzzles** *e.g.* :

- Mass
- Spin [*]
- Inner structure[**]



To learn more about a system, one can [***]:

- Excite it
- Scatter on it
- **Replace one of its building blocks:**

HYPERONS

*C. A. Aidala et al., RMP 85 (2013) 655-691.
** G. A. Miller, PRL 99 (2007) 112001.
** * C. Granados et al., EPJA 53 (2017) 117

Figure extracted from *Hyperon Physics with PANDA at FAIR* Karin Schönning , The 12th International Workshop on Excited Nucleons,

HYPERONS

- Strange hyperon production is governed by **m_s~100 MeV**, probing confinement domain.
- Spin observables are experimentally accessible and distinguish between different production models.
- $\bar{p}p \rightarrow \bar{Y}Y$ production models :
  - Occur through different kinematic channels
  - Have different degrees of freedom

Which are the relevant degrees of freedom?
What is the role of spin?

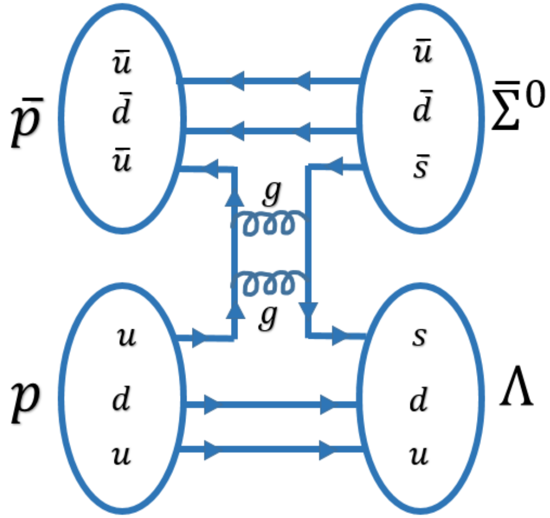


Figure. Quark-Gluon picture

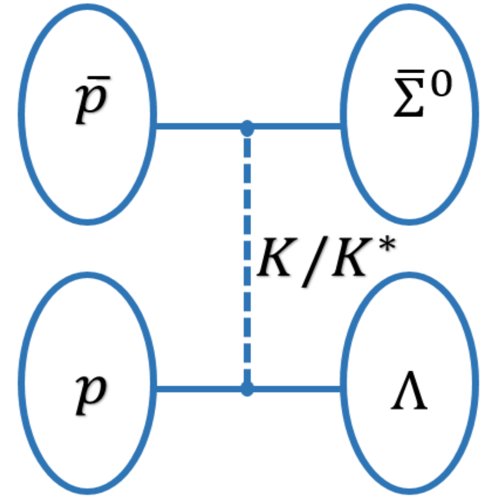


Figure. Meson exchange picture

PREVIOUS $\bar{p}p \rightarrow \bar{Y}Y$ MEASUREMENTS

- Performed mainly at PS185 experiment at LEAR
- $\bar{p}p \rightarrow \bar{\Xi}^{+}\Xi$ measurements were performed with bubble chambers
- Cross sections and spin observables obtained for mainly single-strange $\bar{p}p \rightarrow \bar{Y}Y$ channels
- Little data at $\bar{p}_{beam} > 4$ GeV/c
- No data on Ω

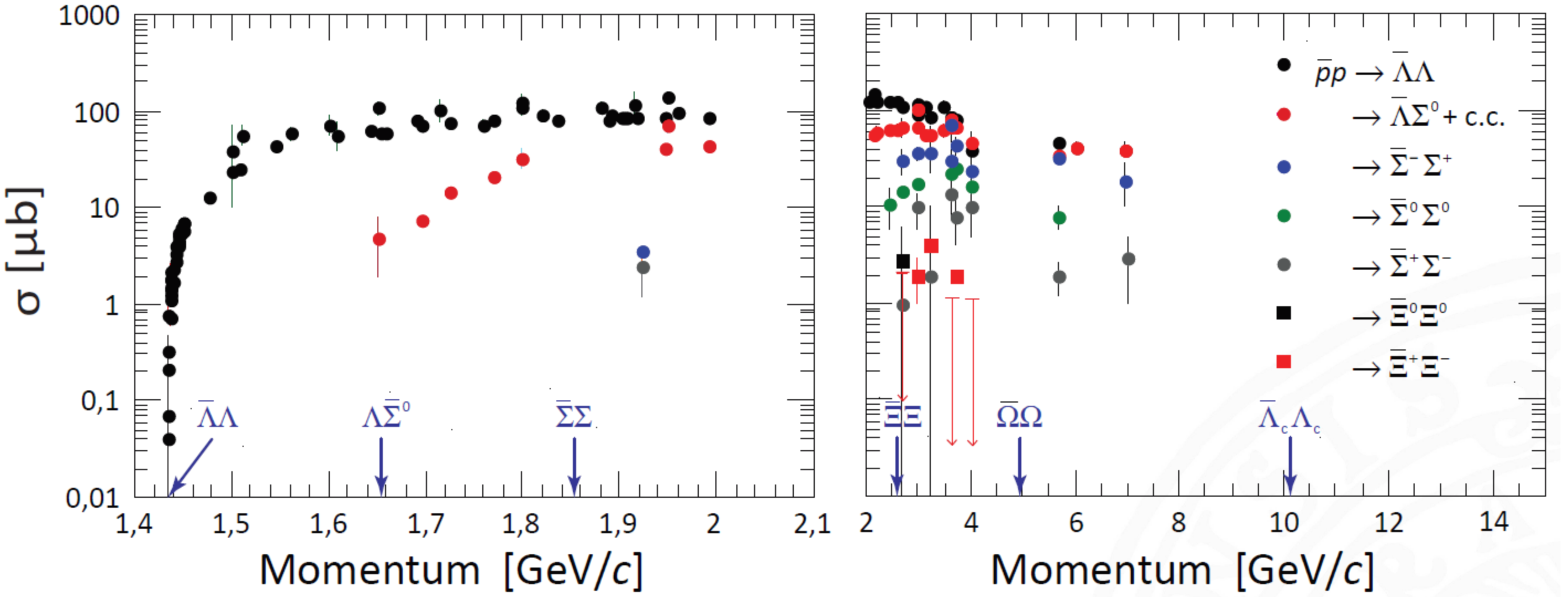


Figure. Johansson T 2003 Proceedings of 8th Int. Conf. on Low Energy Antiproton Physics 95

THE $\bar{\mathbf{p}}\mathbf{p} \longrightarrow \bar{\Sigma}^0\Lambda$ CHANNEL

- Comparisons between channels containing isospin partners such as $\bar{\mathbf{p}}\mathbf{p} \rightarrow \bar{\boldsymbol{\Lambda}}\boldsymbol{\Lambda}$, $\bar{\boldsymbol{\Sigma}}^{\mathbf{0}}\boldsymbol{\Lambda}$ and $\bar{\boldsymbol{\Sigma}}^{\mathbf{0}}\boldsymbol{\Sigma}$, provides information about the role of the isospin in strangeness production.

- Data from PS185 shows a strongly forward peaked differential cross section down to the reaction threshold*:

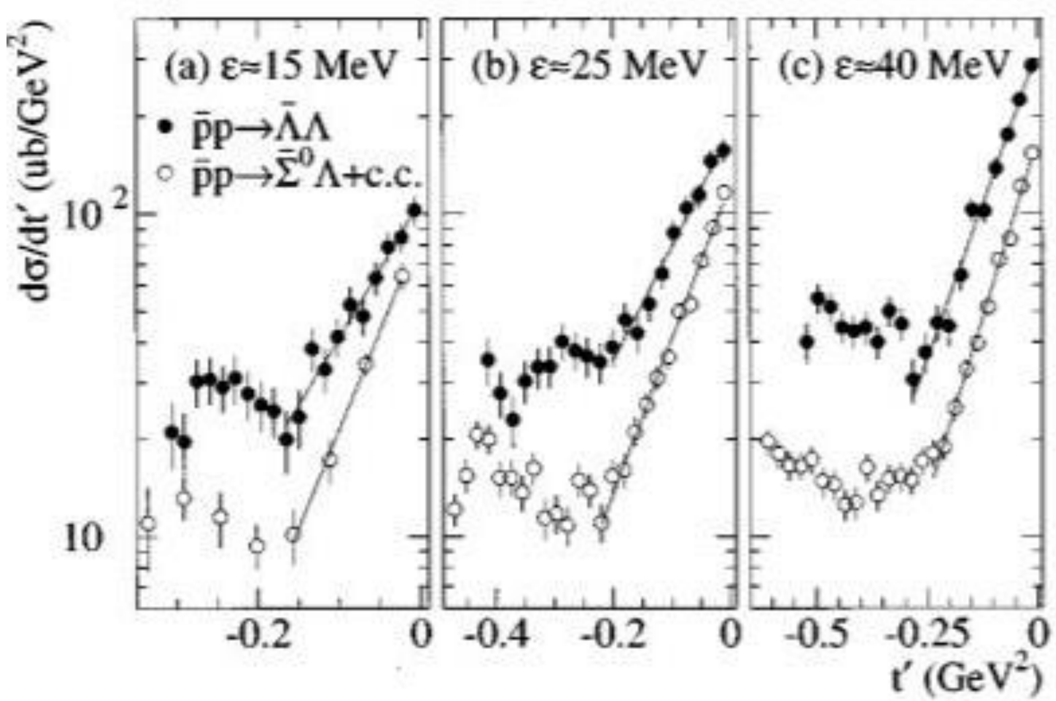
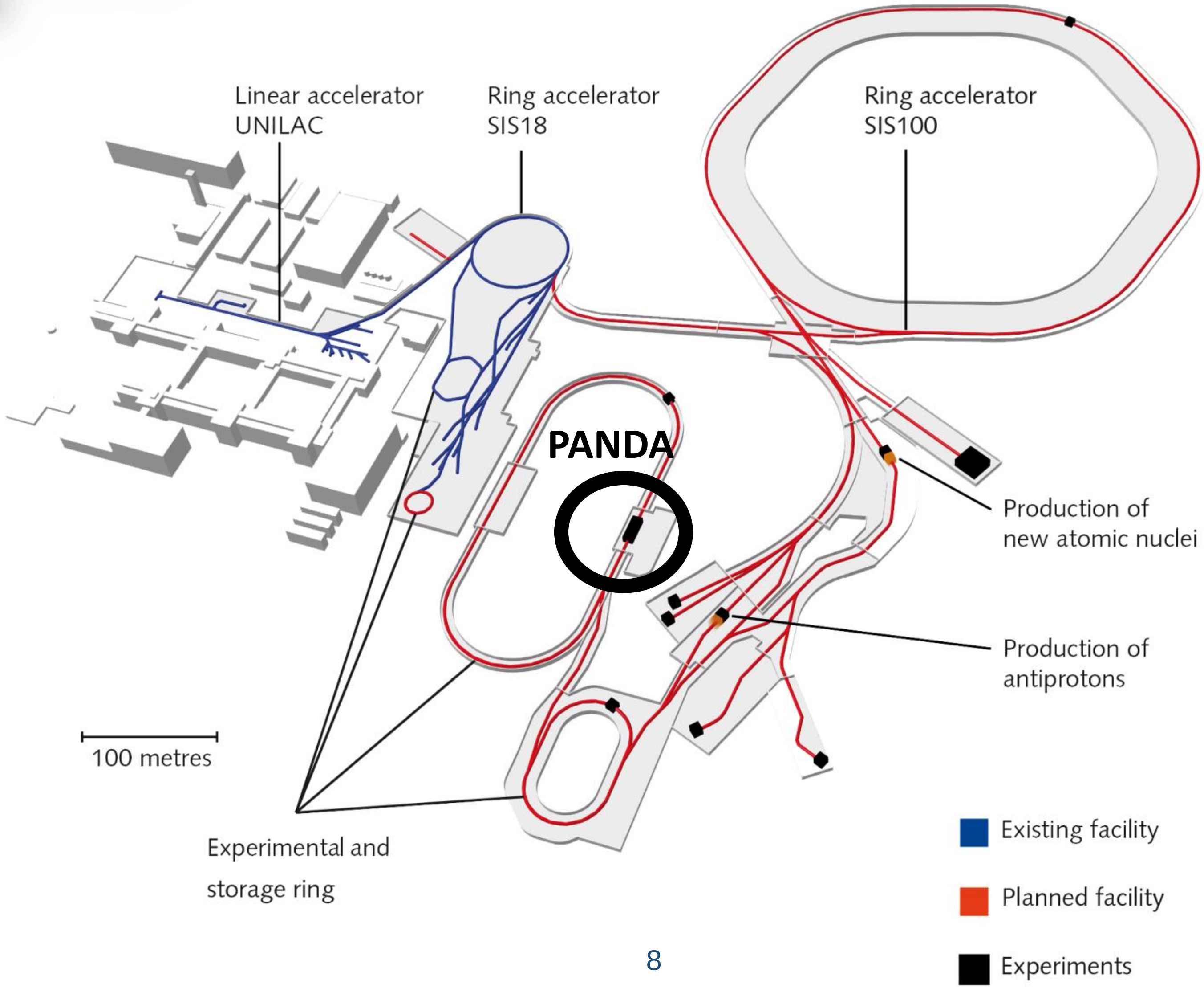
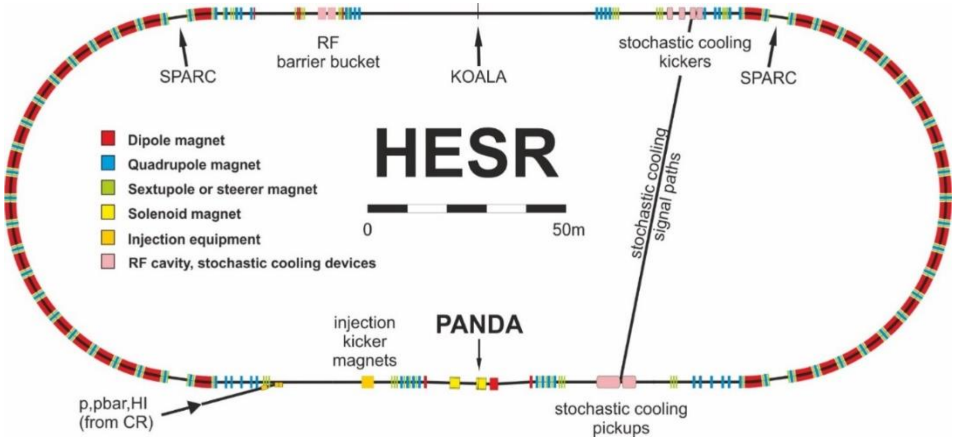


Figure. Cross section parametrization, $\mathbf{p}_{\mathbf{beam}} = 1.771$ GeV/c **

*Barnes, P. D., et. al Physical Review C, (1996) 54(6), 2831.
**H. Becker Nuclear Physics B141 (1978) 48-64



Linear accelerator
UNILAC
Ring accelerator
SIS18
Ring accelerator
SIS100
PANDA
Production of
new atomic nuclei
Production of
antiprotons
100 metres
Experimental and
storage ring
Existing facility
Planned facility
Experiments



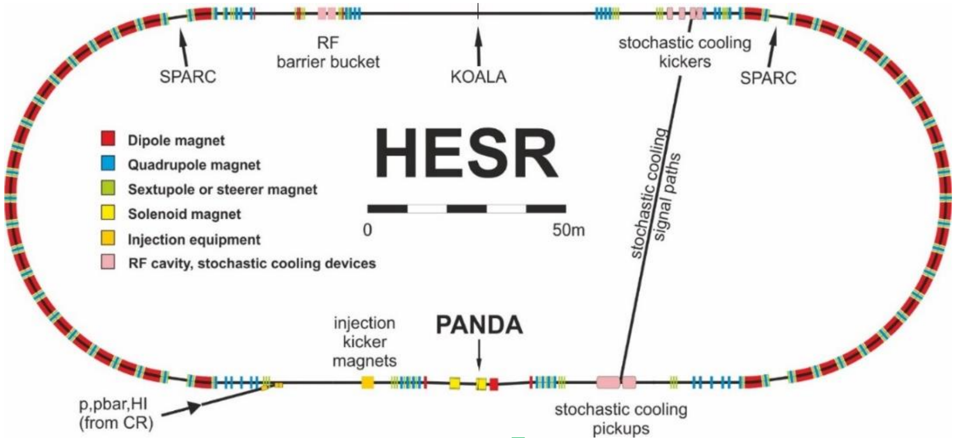
The High Energy Storage Ring (HESR)

- Anti-proton beam within $1.5 < p < 15$ GeV/c
- High resolution mode (Day One)

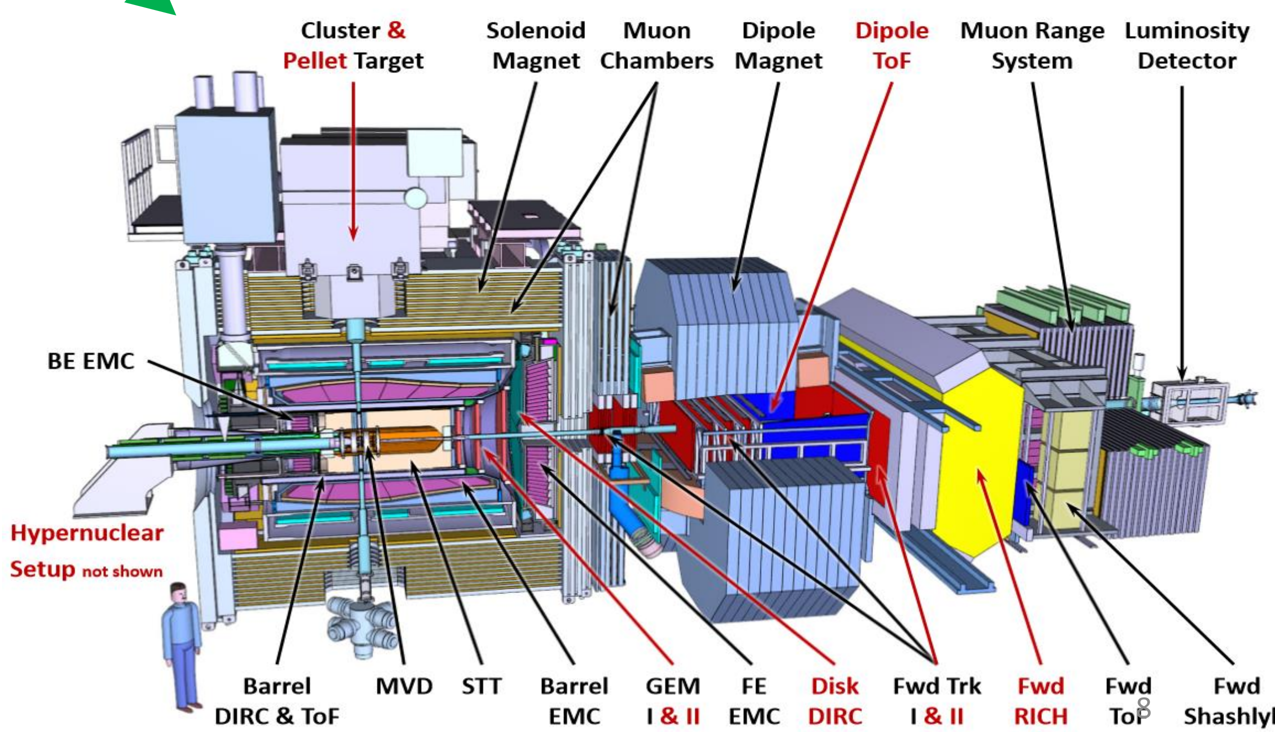
$$L \sim 10^{31}\mathrm{cm^{-2}s^{-1}},\ \mathrm{dp/p} = 4 \times 10^{-5}$$

- High luminosity mode (Design)

$$L \sim 2 \times 10^{32}\mathrm{cm^{-2}s^{-1}},\ \mathrm{dp/p} = 2 \times 10^{-4}$$



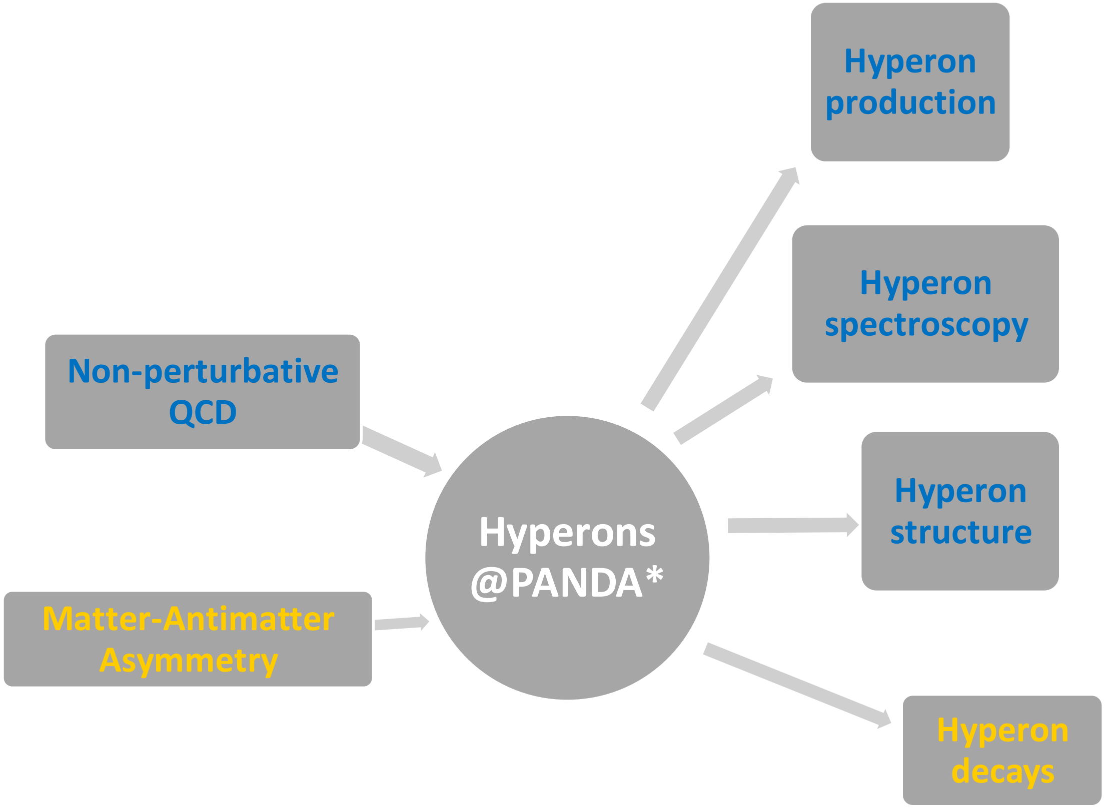
- panda = antiProton ANihilations at Darmstadt.



- Fixed target experiment.
- **Target** and **Forward** spectrometers for 4π coverage with:
  - PID
  - Tracking
  - Calorimetry
  - Muon detection

THE $\bar{\text{P}}$ANDA PHYSICS PROGRAM

- Nucleon structure
- **Strangeness physics**
- Charm and exotics
- Hadrons in nuclei



*Karin Schoenning talk at The 12th International Workshop on Excited Nucleons

FEASIBILITY STUDIES OF $\bar{p}p \rightarrow \bar{Y}Y$ RECONSTRUCTION AT $\bar{\text{P}}$ANDA

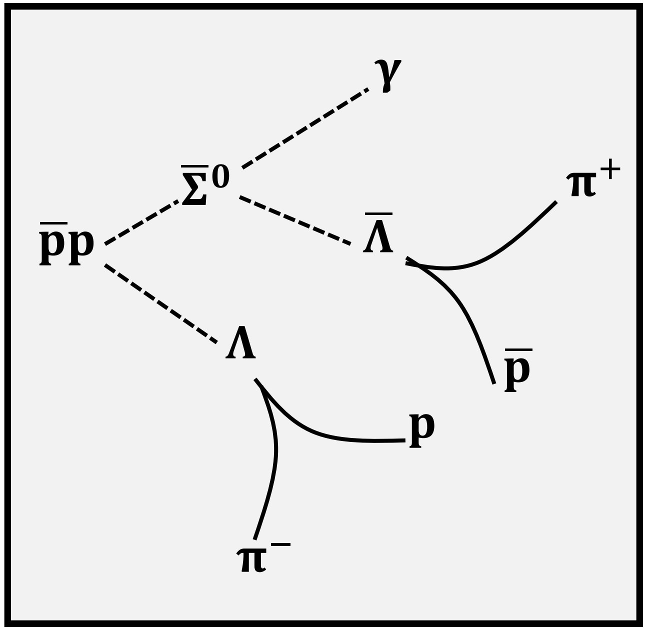
- Single and double strange channels (so far)
- Exclusive event reconstruction (so far)
- Ideal pattern recognition and PID
- Cross section distribution based on data for $\bar{\Lambda}\Lambda$, $\bar{\Sigma}^0\Lambda$ and $\bar{\Xi}\Xi$ at 4.6 GeV/c
- Model prediction for $\bar{p}p \longrightarrow \bar{\Xi}\Xi$ cross-section at 7 GeV/c

p_{beam}	Reaction	σ[μb]	Efficiency (%)	[2]Rate [min^{-1}]
1.64	[1]$\bar{p}p \longrightarrow \bar{\Lambda}\Lambda$	64.0	16	600
1.77	$\bar{p}p \longrightarrow \bar{\Sigma}^0\Lambda$	**10.9**	**?**	**?**
6.0	$\bar{p}p \longrightarrow \bar{\Sigma}^0\Lambda$	**20**	**?**	**?**
4.6	[1]$\bar{p}p \longrightarrow \bar{\Xi}^+\Xi^-$	~ 1	8.2	6.4
7	[1]$\bar{p}p \longrightarrow \bar{\Xi}^+\Xi^-$	~ 0.3	7.9	2.0

[1] W. Ikegami-Andersson (talk at FAIRNESS 2019)
[2] At Day One Luminosity mode: $10^{31}\text{cm}^{-2}\text{s}^{-1}$

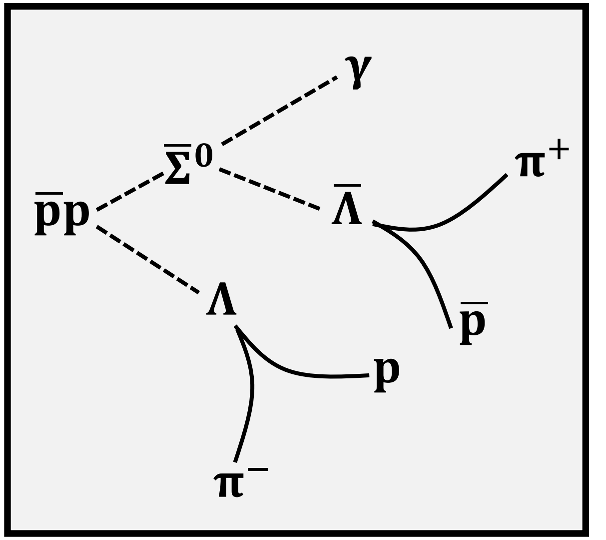
ANALISIS STRATEGY : $\bar{p}p \longrightarrow \bar{\Sigma}^0\Lambda$

Two cases studied for $\bar{p}p \rightarrow \bar{\Sigma}^0\Lambda$:
- 10k events at $p_{beam} = 1.771$ GeV/c
- 10k events at $p_{beam} = 6$ GeV/c

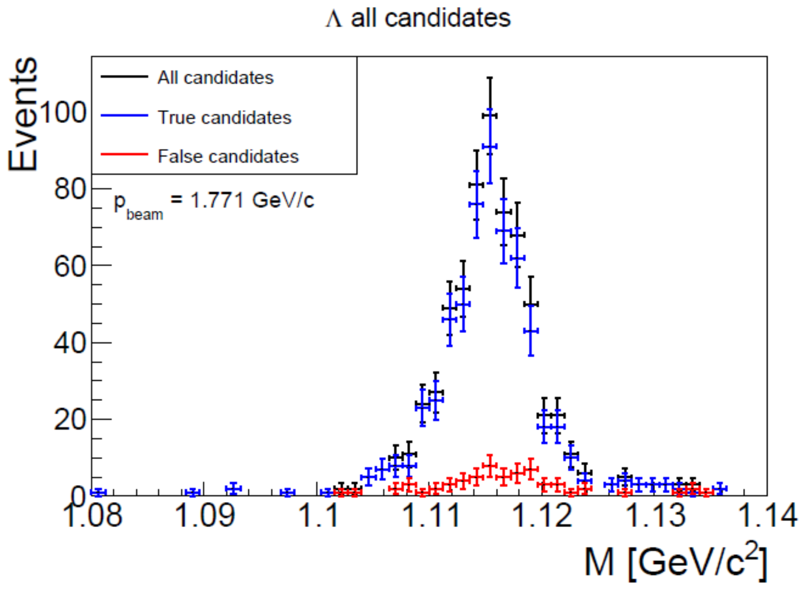


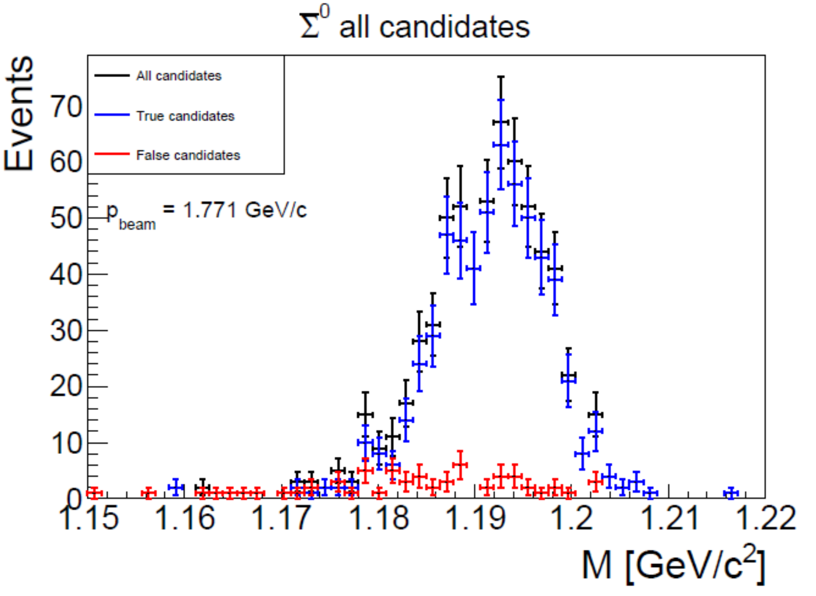
- **Pre-selection**
  - Final state particles identification
  - Photon energy selection
  - $\Lambda/\bar{\Lambda}$ reconstruction
    - Combine all $\pi^+\bar{p}$ / π^-p respectively.
    - Kinematic fit on vertices

ANALISIS STRATEGY : $\bar{p}p \longrightarrow \bar{\Sigma}^0\Lambda$, $p_{beam} = 1.771$ GeV/c



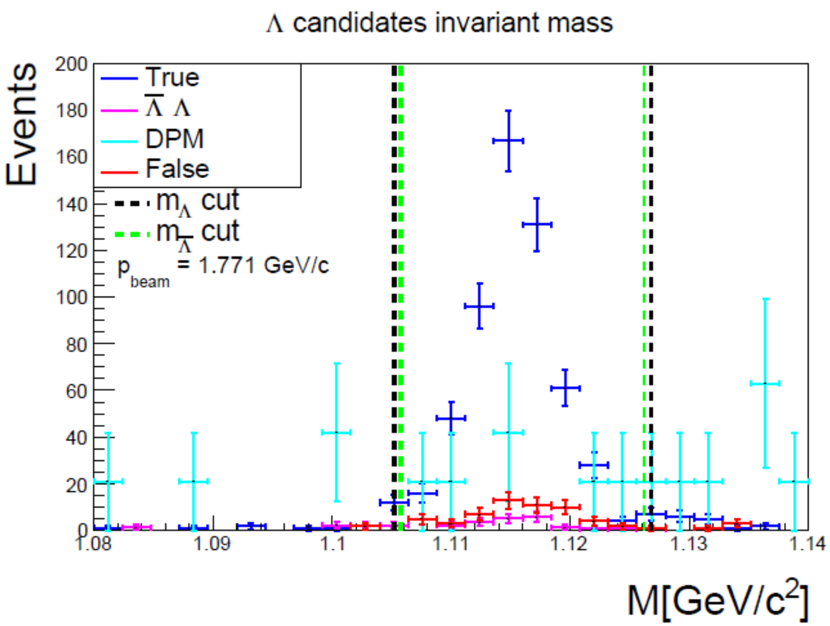
- **Final selection**
  - Pre-selected $\bar{\Lambda}$ and γ combined.
  - $\bar{\Sigma}^0$ and Λ candidates combined.
  - 4-C fit on all the $\bar{\Sigma}^0$ Λ pairs.

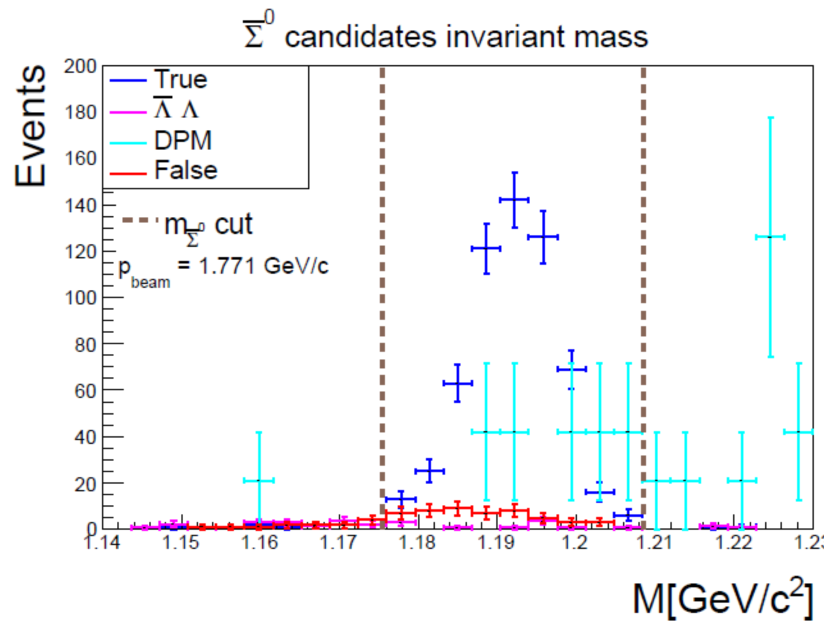




BACKGROUND GENERATION

- Generic hadronic background by DPM generator ($\bar{p}p \longrightarrow$ anything).
- Independent $\bar{\Lambda}\Lambda$ sample used as background
- $\bar{\Sigma}^0\ \Lambda$ and $\bar{\Lambda}\Lambda$ channels were removed from DPM sample.
- Additional cut : 3σ around $m(\bar{\Lambda})$ and $m(\bar{\Sigma}^0)$





FINAL RESULTS, $p_{beam} = 1.771$ GeV/c

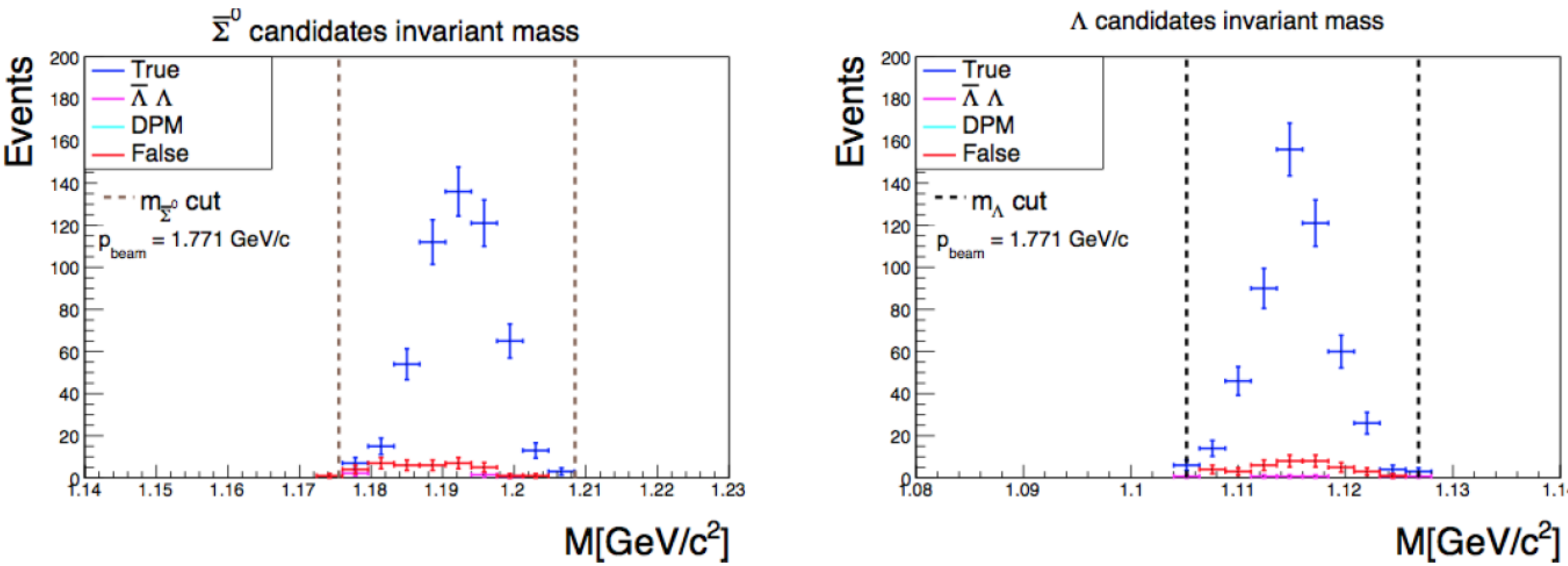


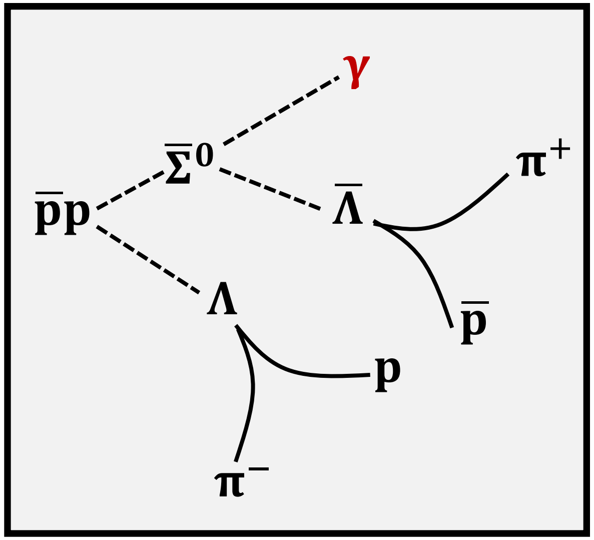
Figure: Signal and background reconstruction. Simulation at p_{beam} = 1.771 GeV/c

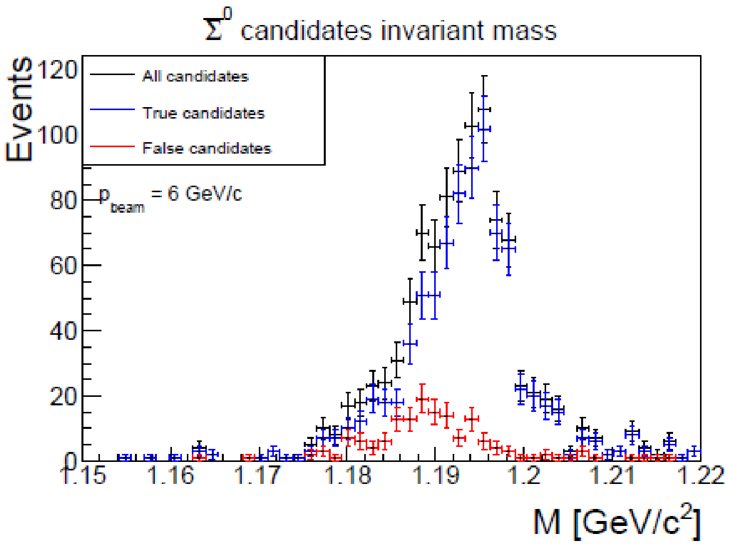
Channel	$\bar{\Sigma}^0\,\Lambda$	Combinatorial	DPM (90% C.L.)	$\bar{\Lambda}\Lambda$
Total	526 ± 23	38	< 50.6	4
S/B	-----------	14	> 11	120
ε(%)	5.3 ± 0.2	0.38	$< 5.1 \times 10^{-4}$	4.0×10^{-5}

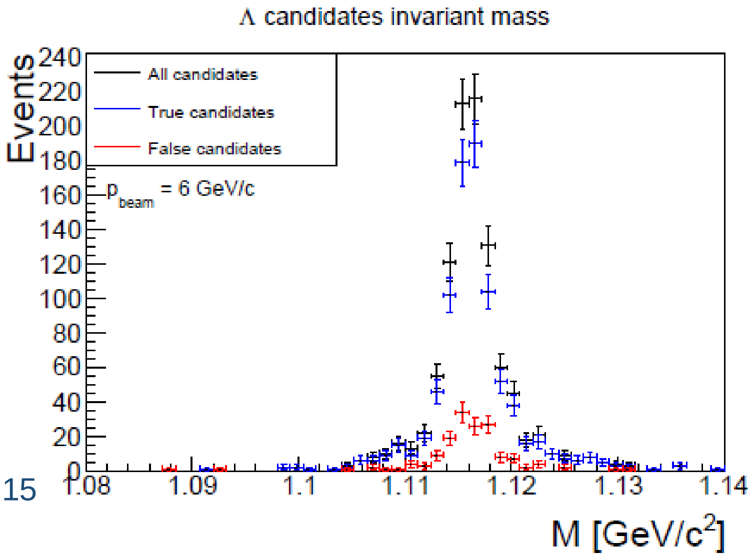
Table: Final efficiencies for the signal and background samples at $p_{beam} = 1.771$ GeV/c

ANALISIS STRATEGY, $p_{beam} = 6$ GeV/c

- **Final selection**
  - Pre-selected $\bar{\Lambda}$ and γ combined
  - Cut in the photon energy boosted to its $\bar{\Sigma}^0$ rest frame.
  - $\bar{\Sigma}^0$ and Λ candidates combined.
  - 4-C fit on all the $\bar{\Sigma}^0\ \Lambda$ pairs

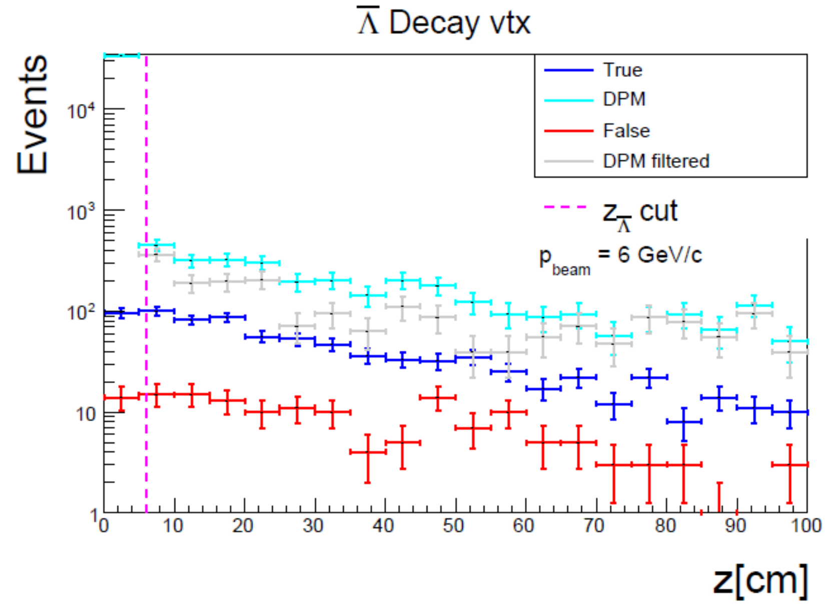


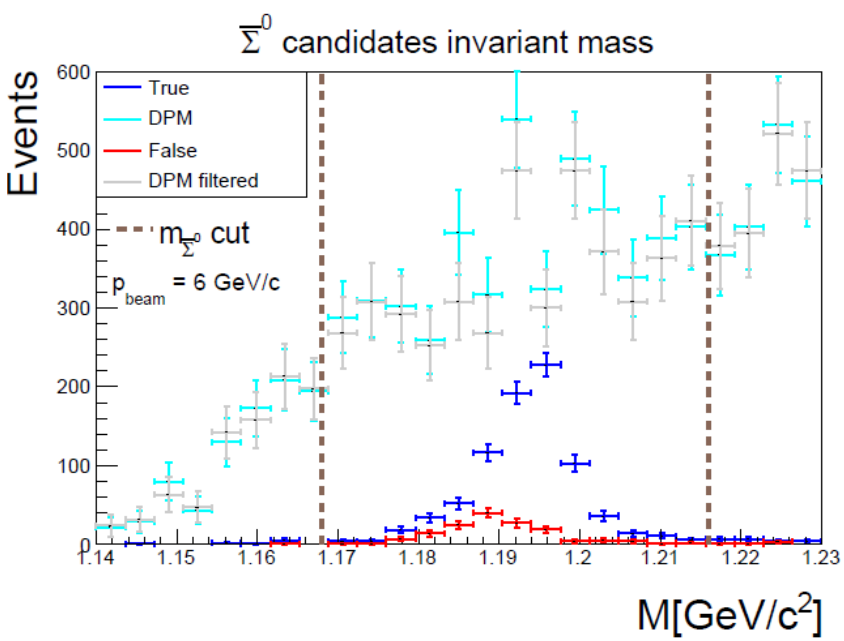


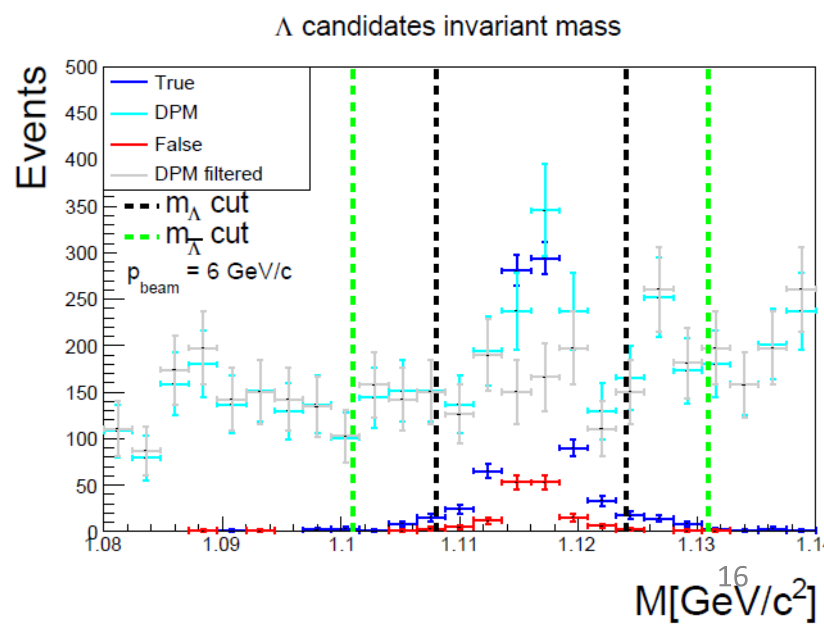


BACKGROUND GENERATION

- DPM sample
- DPM sample filtered from all channels containing Λ and $\overline{\Lambda}$ hyperons
- Additional cuts:
  - 3σ and 5σ around $m(\overline{\Lambda})$ and 5σ $m(\overline{\Sigma}^0)$ respectively
  - $\overline{\Lambda}$ decay vertex > 6 cm







FINAL RESULTS, $p_{beam} = 6$ GeV/c

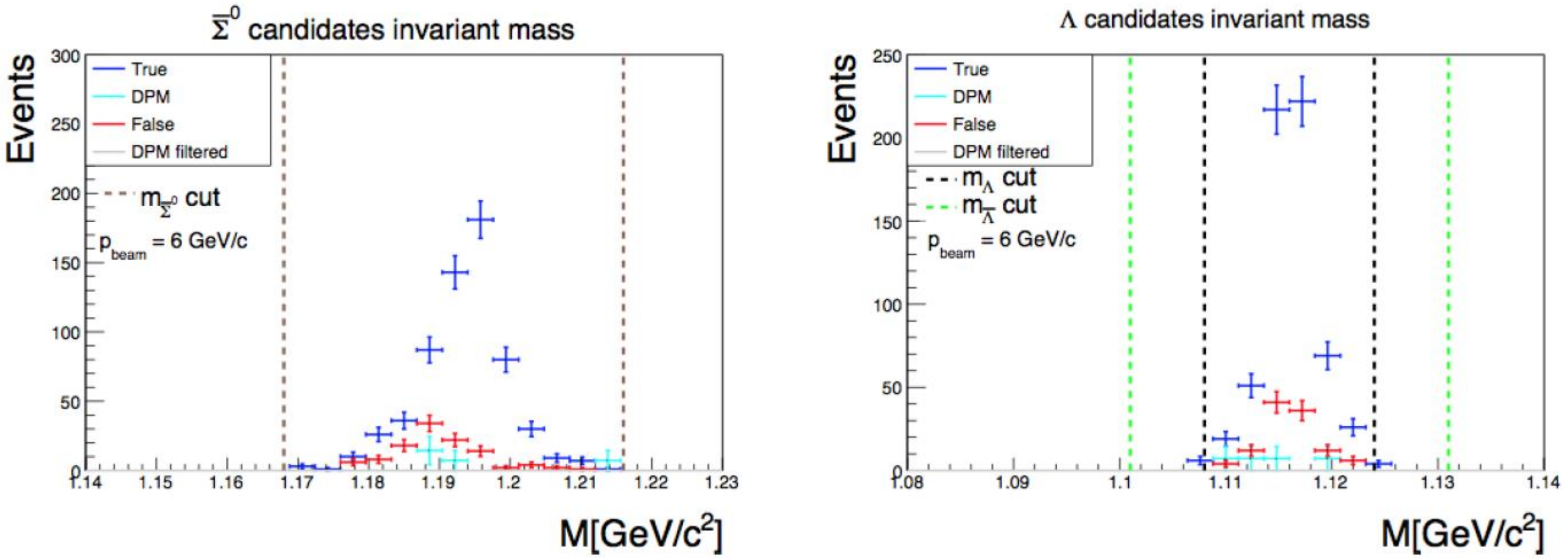


Figure: Signal and background reconstruction. Simulation at p_{beam} = 6 GeV/c

Channel	$\bar{\Sigma}^0\,\Lambda$	Combinatorial	DPM	DPM filtered (90%C.L.)
Total	614 ± 25	111	30	< 18
S/B	---------	5.5	20.7	> 34.7
ε(%)	6.1 ± 0.3	1.1	3.0×10^{-6}	$< 3.9 \times 10^{-6}$

Table: Final efficiencies for the signal and background samples at $p_{beam} = 6$ GeV/c

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- Single and double strange channels (so far)
- Exclusive event reconstruction (so far)
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1.77	**$\bar{p}p \longrightarrow \bar{\Sigma}^0\Lambda$**	**10.9**	**5.3**	**32**
6.0	**$\bar{p}p \longrightarrow \bar{\Sigma}^0\Lambda$**	**20**	**6.1**	**96**
4.6	[1]$\bar{p}p \longrightarrow \bar{\Xi}^+\Xi^-$	~ 1	8.2	6.4
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[1] W. Ikegami-Andersson (talk at FAIRNESS 2019)
[2] At Day One Luminosity mode: $10^{31}cm^{-2}s^{-1}$

CONCLUSIONS

- Hyperons studies can provide valuable information to complement our knowledge of the strong interaction.

- The $\overline{\text{P}}$ANDA experiment aims to increase the available data on single and multi-strange $\bar{p}p \rightarrow \bar{Y}Y$ processes.

- Feasibility studies of event reconstruction have been performed showing that high exclusive reconstruction efficiencies will be achievable at $\overline{\text{P}}$ANDA starting from Day One.

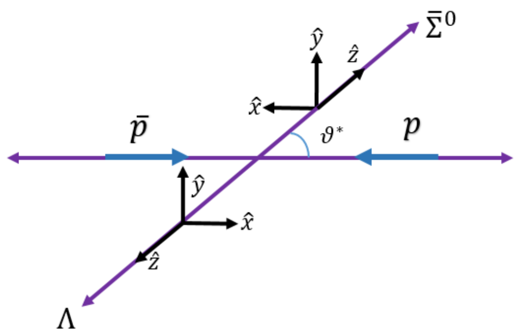
Thank you!

Back-up

Previous measurements: $\bar{p}p \longrightarrow \bar{\Sigma}^0\Lambda$

The cross-section was parametrization in terms of the reduced four-momentum transfer

$$t' = 2pq(\cos\vartheta^* - 1)$$



ϑ^* =: c.m. scattering angle of the antihyperon
p =: incoming $\bar{p}$ c.m. momentum
q =: outgoing $\bar{\Sigma}^0$ c.m. momentum

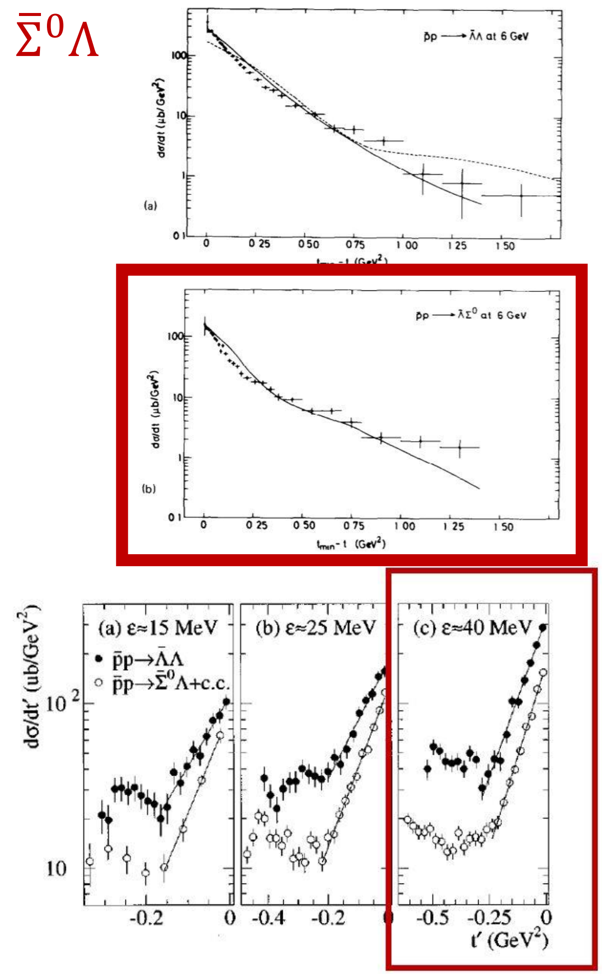


Figure. Cross section parametrization, $\mathbf{p_{beam}} = 1.771$ GeV/c * (top) and $\mathbf{p_{beam}} = 6$ GeV/c (bottom)**

*H. Becker Nuclear Physics B141 (1978) 48-64
E. Klempt et al. Physics Reports 368 (2002) 119–316

Why hyperons?

- Strange hyperon production is governed by **m_s~100** MeV, probing confinement domain.
- Spin observables are model dependent and experimentally accessible *e.g.* **polarization**:

All ground state hyperons (Y) decay weakly* → Parity is violated.
Consider:

$$Y\left(\frac{1}{2}\right) \to B\left(\frac{1}{2}\right) + M(0)$$

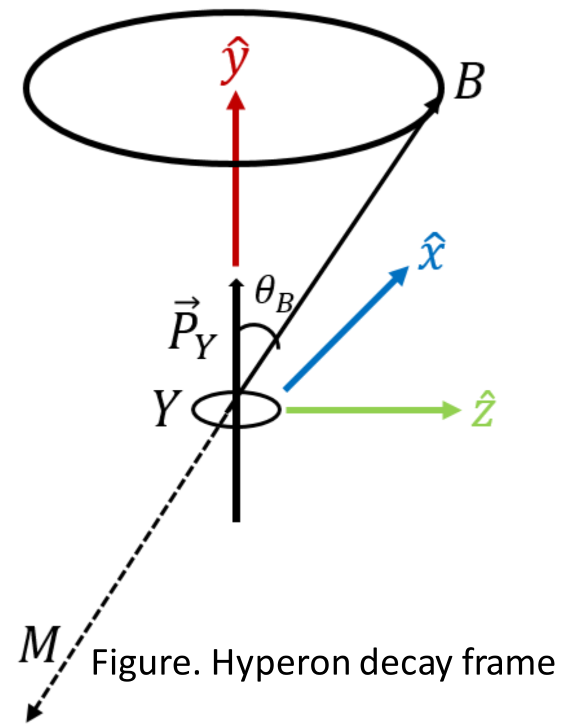


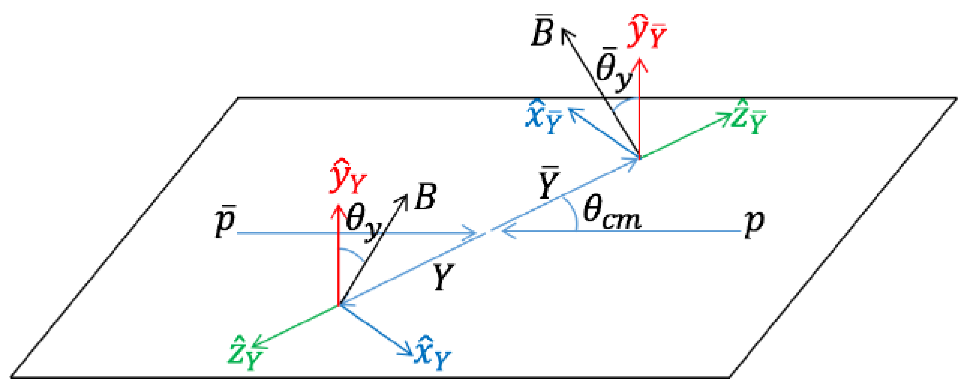
Figure. Hyperon decay frame

- Decay angular distribution given by

$$I(\cos\theta_B) \propto (1 + \alpha P_Y \cos\theta_B)$$

- Where :

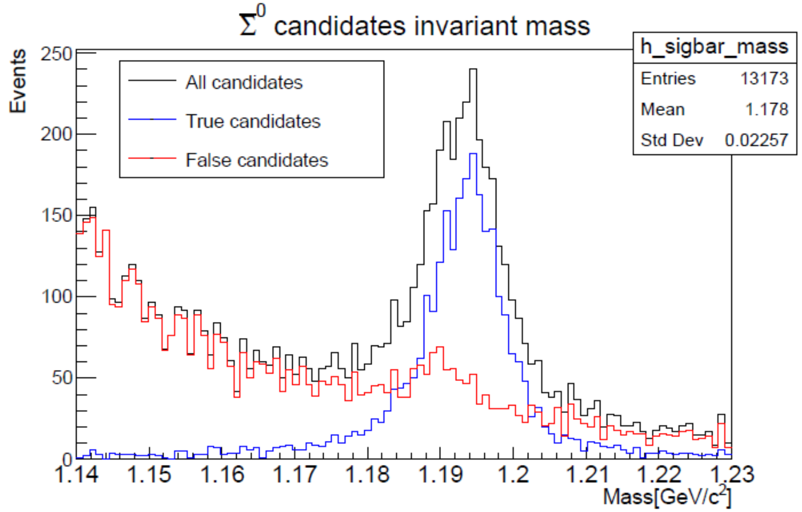
α : Asymmetry parameter (known)
$\cos\theta_B$: Baryon emission angle (measured)
***P_Y* : Hyperon polarization (extracted!)**

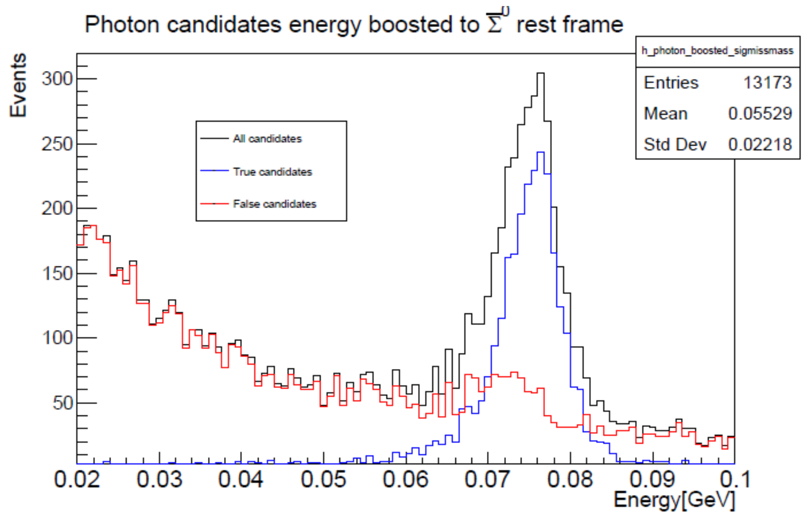


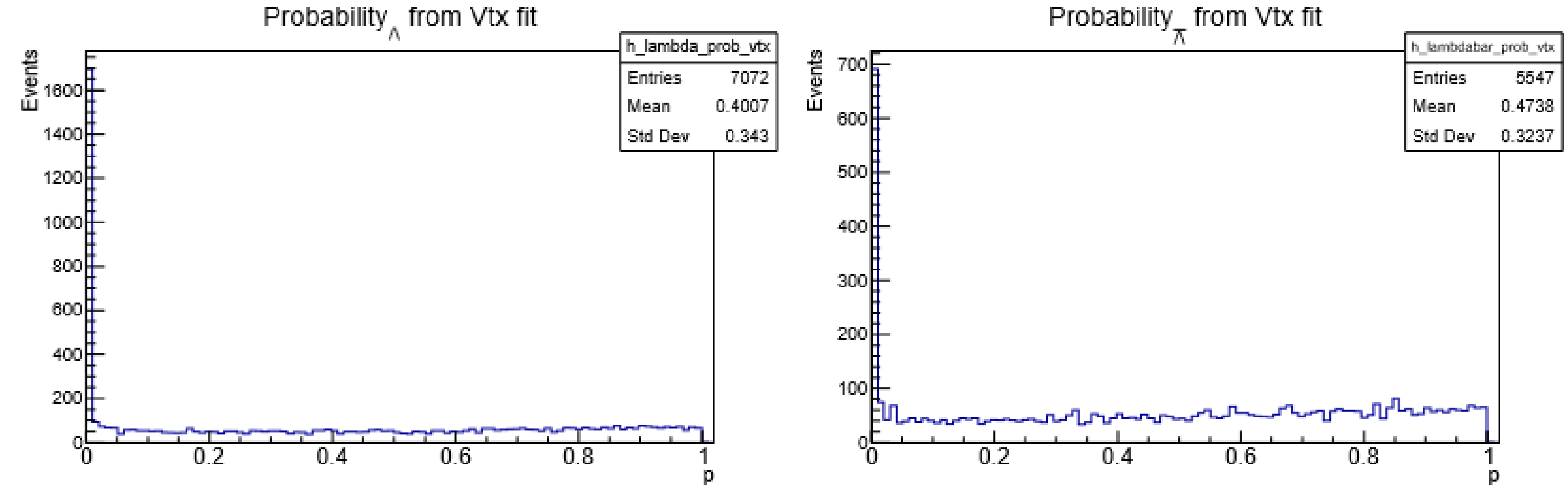
*Except for the $\bar{\Sigma}^0$, which decays electromagnetically

Exclusive event selection
$\mathbf{p_{beam}}$ = 6 GeV/c

- Pre-selected $\overline{\boldsymbol{\Lambda}}$ and $\boldsymbol{\gamma}$ combined.
- Cut in the photon energy boosted to its $\overline{\boldsymbol{\Sigma}}^{\mathbf{0}}$ rest frame.
- $\overline{\boldsymbol{\Sigma}}^{\mathbf{0}}$ and $\boldsymbol{\Lambda}$ candidates combined.
- 4-C fit on all the $\overline{\boldsymbol{\Sigma}}^{\mathbf{0}}$ $\boldsymbol{\Lambda}$ pairs,
- Reject p < 0.01.
- Best pair selection according to χ^2 value.

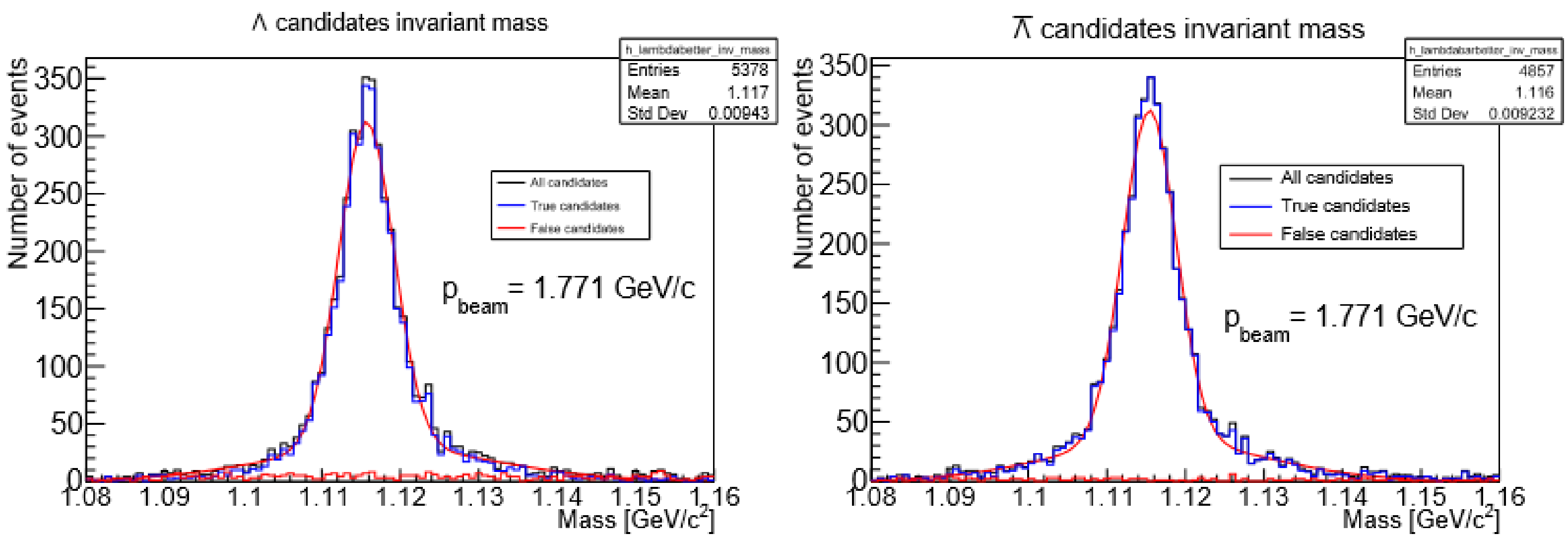


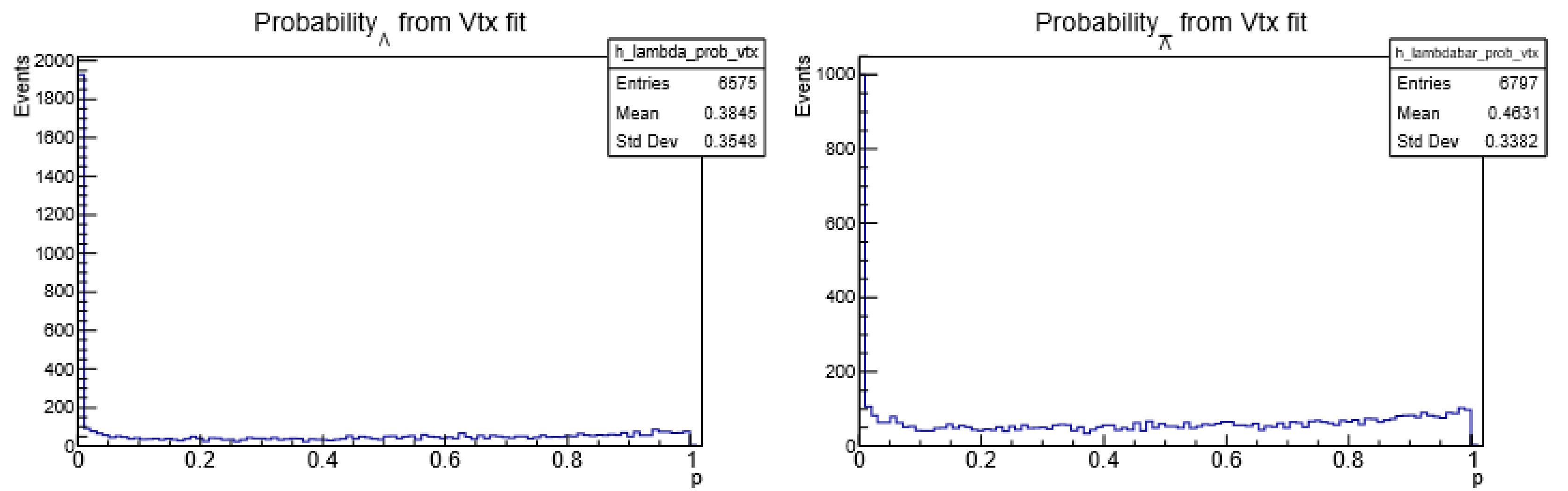




(a) **(b)**

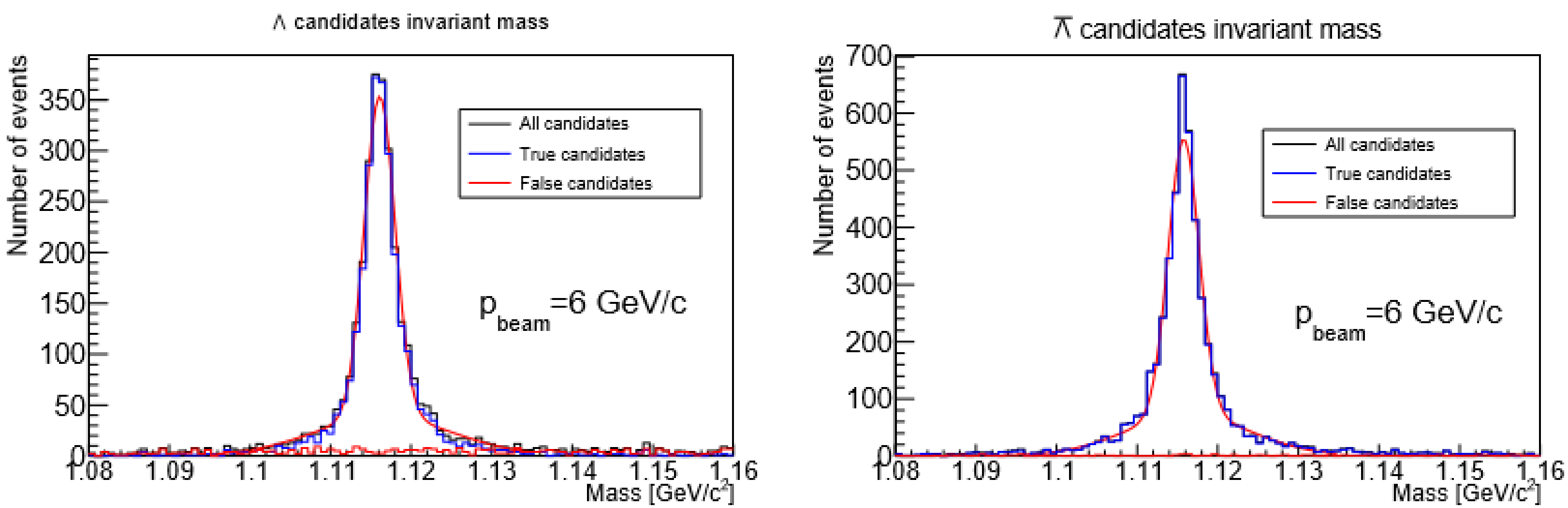
Figure 4.18: Probability distribution corresponding to the vertex fit performed on the **(a)** Λ and **(b)** $\bar{\Lambda}$ respectively. Beam momenta p_{beam} = 1.771 GeV/c.





(a) **(b)**

Figure 4.20: Probability distribution corresponding to the vertex fit performed on the **(a)** Λ and **(b)** $\bar{\Lambda}$ respectively. Beam momenta p_{beam} = 6 GeV/c.



Channel	$\bar{\Sigma}^0\Lambda$	DPM	$\bar{\Lambda}\Lambda$
Size	10^4	10^7	10^5
$\sigma[\mu b]$	11	95,000	80
w	1	22	0.73

Channel	$\bar{\Sigma}^0\Lambda$	DPM	DPM filtered
Size	10^4	10^7	9 X 10^6
$\sigma[\mu b]$	20.0	59,000	57,690
w	1	7.4	7.7

$$\epsilon = \frac{N_{reconstructed}}{N_{simulated}} \times 100\%$$

$$w_{anything} = \frac{N_{signal}}{N_{anything}} \frac{\sigma(\bar{p}p \to anything)}{\sigma(\bar{p}p \to \bar{\Sigma}^0\Lambda) BR(\bar{\Sigma}^0 \to \bar{\Lambda}\gamma) BR(\bar{\Lambda} \to \bar{p}\pi^+)^2}$$

$$w_{\bar{\Lambda}\Lambda} = \frac{N_{signal}}{N_{\bar{\Lambda}\Lambda}} \frac{\sigma(\bar{p}p \to \bar{\Lambda}\Lambda) BR(\bar{\Lambda} \to \bar{p}\pi^+)^2}{\sigma(\bar{p}p \to \bar{\Sigma}^0\Lambda) BR(\bar{\Sigma}^0 \to \bar{\Lambda}\gamma) BR(\bar{\Lambda} \to \bar{p}\pi^+)^2}$$

$$\dot{N}_{rec} = \sigma(\bar{p}p \to \bar{\Sigma}^0\Lambda) \times BR(\bar{\Sigma}^0 \to \bar{\Lambda}\gamma) \times BR(\bar{\Lambda} \to \bar{p}\pi^-)^2 \times \mathcal{L} \times \epsilon$$

Device	Polar angle coverage
MVD (Discs)	3° - 40°
MVD (Half-shells)	40° - 150°
STT	22° - 140°
GEM	0° - 22°
FT	0° - 10°

Table 4.4: Angular coverage of the principal tracking devices at the Target and Forward spectrometer at $\overline{\text{P}}$ANDA.

Device	Polar angle coverage
Barrel DIRC	22° - 140°
Forward endcap DIRC	5° - 22°
Barrel TOF	22° - 140°
RICH	5° - 22°

Table 4.5: Angular coverage of the principal PID devices in the Target and Forward spectrometers at $\overline{\text{P}}$ANDA.

Device	Polar angular coverage	Energy coverage (GeV)
Backward	151.4° - 169.7°	0.01 - 0.7
Barrel	22° - 140°	0.01 - 7.3
Forward	5° - 23.6°	0.01 - 14.6

Table 4.6: Angular acceptance and energy ranges at which each part of the calorimeter are used as PID device.